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Mars Manned Transportation Vehicle

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SUMMARY

The Manned Mars Mission Working Group (1985), directed by NASA Marshall Space Flight Center, addressed the technology issues required to support manned Mars missions in the next century. The various facets of a manned Mars mission were addressed by individual subgroups. The Mars Surface Infrastructure Subgroup addressed the capabilities and the equipment that needed to be landed to support a permanently manned Mars surface base. A key objective of this base is to carry out surface geological exploration of the planet. As part of this study, the NASA Lewis Research Center developed a design concept for this vehicle that used hydrogen-oxygen fuel cells as the primary power system. This paper presents the results of a study to identify and describe a viable power system technology for a surface transportation vehicle to explore the planet. A number of power traction systems were investigated, and it was found that a regenerative hydrogen-oxygen fuel cell appears to be attractive for a manned Mars rover application. Mission requirements were obtained from the Manned Mars Mission Working Group. Power systems weights, power, and reactants requirements were determined as a function of vehicle weights for vehicles weighing from 6000 to 16 000 lb (2722 to 7257 kg), (Earth weight). The vehicle performance requirements were: velocity, 10 km/hr; range, 100 km; slope climbing capability, 30° uphill for 50 km; mission duration, 5 days; and crew, 5. Power requirements for the operation of scientific equipment and support system capabilities were also specified and included in this study.

The concept developed here would also be applicable to a Lunar based vehicle for Lunar exploration. The reduced gravity on the Lunar surface, (over that on the Martian surface), would result in an increased range or capability over that of the Mars vehicle since many of the power and energy requirements for the vehicle are gravity dependent.

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INTRODUCTION

Man has an insatiable drive to explore new worlds, and in due time, colonize the planets. The actual scenario for accomplishing this is open to speculation, but the first step might be to revisit the moon and establish a permanent colony on the lunar surface. A next logical step might be to visit and explore our neighbor Mars. With an established colony on the Martian surface, the exploration could proceed in a number of ways. One possible means would utilize orbiting satellites to survey Martian resources from orbit. However, to carry out a complete exploration of the planet would require human exploration in inhabited vehicles. The progress of human surface exploration should be many faceted. The function to be carried out by humans on the surface may include verifying satellite data, carrying out detailed surface exploration by emplacing instruments to study the planetary environment, and others. To carry out this exploration would require human-operated surface vehicles capable of transporting scientific crews and equipment to collect samples as needed, test them on the spot, collect additional samples as needed, carry out other scientific experiments, and return them to the main base for further study. NASA Lewis investigated the concept for such vehicle and studied the requirements for the power system needed to power the vehicle. Hydrogen-oxygen fuel cells were found to provide a viable concept for such a transportation system.

This paper presents the results of a study to identify and describe the power system technology which would meet the requirements for a Mars surface exploration vehicle. Mission requirements for the manned transportation system were determined by the Manned Mars Mission Working Group, (Surface Infrastructure Subgroup). A vehicle with a 100 km range, speed of 10 km/hr, slope climbing ability of 30° for 50 km, a mission duration of 5 days and a crew size of 5 was felt to meet the requirements for geological exploration of the Martian surface. Power requirements for the operation of scientific and the other support equipment are also specified and included in sizing of the power system for the vehicle.

Historically, the goals and objectives of the space program have been to promote the development and use the new technologies. Technological advancements are critical for the future progress in space, especially for manned operations. The establishment of planetary settlements should serve as impetus to relevant technology development and a vision for new technologies.

FUEL CELL POWER SYSTEM

The viability of surface transportation of other mobile planetary systems will, to a large extent, depend upon availability of a feasible power system that is compatible with the vehicle mission requirements. Size, weight, volume and the operating characteristics of the power system will affect the design and the performance of the vehicle to a very large degree. A hydrogen-oxygen fuel cell represents a strong candidate for such a power system. The fuel cell power system of the Mars transportation vehicle evaluated here is an evolutionary extension of the current power system defined for the Space Shuttle orbiter. The current electrical power system of the Shuttle consists of three hydrogen-oxygen alkaline electrolyte fuel cells, with the hydrogen and oxygen reactants stored at cryogenic temperature and supercritical pressure. The system is rated at a maximum continuous power of 21 kW and has a nominal lifetime of 7 days (ref. 1). Detailed operating characteristics of the Shuttle fuel cell are presented in table I. It is this state-of-the-art system that represents the basis of the power system for the manned Mars transportation system.

FUEL CELL POWER PLANT (FCP)

System Characteristics

The fuel cell module for our concept consists of hydrogen and oxygen (reactants) tanks, an integrated fuel cell and an electrolyzer cell stack that is at the base. Figure 1 shows a Space Shuttle auxiliary fuel cell power system developed by The United Technology Power Systems, Inc., to increase the orbiter power/energy inventory.

The characteristics of this system, which represent near term state of the art, are such that the weight, size, volume and power/energy can be matched to many planetary surface mobile systems requirements. This technology can be applied to arrive at a power system-vehicle concept for the manned Mars surface transportation system.

In this system, hydrogen and oxygen react to form water, delivering electrical power to the vehicle drive motors located at the individual wheels. The water is stored onboard for return to the base and reused because it is deemed too valuable to discard. The oxygen directly enters the fuel cell stack. Using the recycle loop, product water is removed from the hydrogen side of the fuel cell as vapor. This gas stream mixes with the incoming hydrogen and enters the condensers where its temperature is reduced and a certain fraction of water vapor is condensed (ref. 2). The gas and liquid phases are separated in the hydrogen pump/separator. The gas is recirculated to the fuel cell and the liquid water is delivered to the storage tank. Upon returning from the mission, the water is electrolyzed at a facility at the Mars base. The electrolysis facility will receive power from an external source, and will produce oxygen and hydrogen that are pressurized and pumped into the respective tanks on the vehicle.

The oxygen storage tanks may be integrated with the open cycle life support system and the waste heat from the hydrogen-oxygen fuel cell could be used for internal thermal control of the vehicle, resulting in significant savings in weight, power and internal volume.

Design Considerations

Martian terrain/surface characteristics. - The rolling resistance of the Mars transportation vehicle was determined for 32 in. diameter Lunar Rover x-type wheels in loose sand (refs. 3 and 4). This resulted in a rolling resistance coefficient of 0.32 that is felt to be conservative for this application. A 30° uphill slope was selected as a design requirements for the Mars transportation vehicle.

Energy requirements. - The power system was designed to fulfill certain scientific and operational requirements such as surface core drilling/sampling, and providing the power to run instruments and experiments during its cruising missions. The energy budget, which determines the reactants requirements to overcome the rolling resistance, the increase in potential energy due to slope climbing and the operation of internal energy and external functions requiring energy expenditure. An extra 25 percent of energy budget was added for contingency reasons. Table II presents the Mars transportation vehicle requirements.

Power requirements. - The hydrogen-oxygen fuel cell with technology attributes projected from that of the Shuttle orbiter system to represent year 2000 technology was used to determine the power system weights, volume and operating characteristics. The categories of considered include the power and energy hardware, waste heat rejection, radiator, reactants, power management and distribution (PMAD), and electric drive motors. Also, 50 percent power reserve is added to the fuel cell for contingency purposes and to accommodate a reactant supply trailer to extend the mission range if desired. The power system requirements are listed in table III.

The vehicle power requirements are determined by the rates of energy expenditure to meet the rolling resistance and the slope climbing requirements, in addition to the internal power requirements while the vehicle is underway. These items determine the power system size. Experimental/internal requirements, when the vehicle is stationary at a site, are easily met if the "moving" requirements are used to size the power system.

VEHICLE DESCRIPTION

The Vehicle Trade-Off

Power system weights, power requirements, and reactants requirements were determine as a function of vehicle weight for vehicles weighing 6000 to 16 000 lb (2722 to 7257 kg). Power requirements for the operation of scientific equipment and support system are also specified and included in this study. The data used represent post year 2000 technology. The fuel cell system design parameters are listed in table IV.

The Vehicle Fuel Cell Power System

The fuel cell module for this concept consists of hydrogen and oxygen reactant tanks, an integrated fuel cell, and an electrolyzer cell stack that is at the permanent base. Hydrogen and oxygen are combined in the fuel cell (at the vehicle) to produce electricity and water. The power system weight as function of the vehicle weight is shown in figure 2. It includes power dependent hardware, energy dependent hardware, and reactants' weights.

Figure 3 shows the power system weight in percent as a function of the vehicle weight. As figure 3 shows, the fuel cell power system comprises 38 percent of the vehicle weight for a lightweight (6000 lb/2722 kg) vehicle, but drops to 25 percent for a heavier (16 000 lb/7257 kg) vehicle.

The power system for the vehicle weighing 16 000 lb (7257 kg) is present in table V.

A pictorial of the power system is shown in figure 4. The material used for the reactant storage tanks was Kevlar 49 (ref. 5), because it offers a significant weight saving over the conventional metal tanks. The reactants are stored at cryogenic temperature and supercritical pressure on spherical shaped tanks.

The electrolysis unit at the base is used to electrochemically decompose water into gaseous hydrogen and oxygen for use of the fuel cell. The hydrogen and oxygen products will be pumped into the reactants respective tanks. Figure 5 shows the energy budget for the 7257 kg (16 000 lb) vehicle and figure 6 gives the power budget for this vehicle.

The characteristics of the fuel cell power system are given in figure 7 and the typical electrolyzer module characteristics are given in figure 8.

An artist concept of what such vehicle might look like is shown in figure 9.

The support trailer will carry hydrogen and oxygen tanks to either extend the mission or cover other types of contingencies. If it were desired to extend the mission on the capability of the surface exploration vehicle, additional reactants could be stored and carried in the trailer that could more than double the range and duration of the vehicle. The reserve, that was added to the power budget, is more than sufficient to accommodate a trailer carrying the required reactants.

Another possibility is to "palletize" the fuel cell power system for mounting in the vehicle. In this case the entire system could be removed and replaced with a newly "charged" system at "way stations" or outposts where the exchange could be made.

This particular study was concerned with the special case of the Mars geological exploration vehicle. Many other mobile surface systems would be required to support a mature Mars base or colony. These might consist of inter and intra base personnel transportation systems, heavy and light cargo vehicles, construction and mining equipment such as bulldozers and excavators, and possible mobile cranes. Although not studied in detail it is felt that the hydrogen-oxygen fuel cell power system concept proposed here is also a viable power system concept for these applications.

CONCLUSIONS

This study has demonstrated the viability of a power system for a Mars surface exploration vehicle. As the vehicle weight increases from 6000 to 16 000 lb (2722 to 7257 kg) the percent of vehicle weight taken by the power system drops from 38 to 25 percent.

At the lower vehicle weight it is felt that the power system mass fraction is too large to be a viable concept. Additional benefits of the system are that the heat generated by the fuel cell can be used for the thermal control of the vehicle. Also the oxygen and water tanks can be integrated with the life support system to provide breathing oxygen and water for the crew. This type of life support/fuel cell integration would result in a more weight efficient vehicle design. The support trailer will provide the crew with the extra oxygen and hydrogen storage tanks for extending the mission. The weights and sizes of the tanks would depend on the vehicle weight. The hydrogen and oxygen reactants are stored at cryogenic temperature and supercritical pressure on the spherical shaped tanks.

The hydrogen-oxygen fuel cell is able to meet the requirements as a power system for the Mars surface transportation vehicle. The actual vehicle weight design will depend on the mission definition, system operations and design parameters.

Many configurations of the fuel cell power system for planetary surface mobile systems are possible. The concept presented here integrated the fuel cell power system into the vehicle, the electrolyzer at the permanent base and the vehicle returning to the base for "recharging" of the reactants tanks. Range extension in this case was postulated by means of the reactants trailer.

The concept developed here would also be applicable to a Lunar Rover for lunar surface exploration. The reduced gravity on the lunar surface, over that on Martian surface, would result in an increased range or capability over that of the Mars vehicles since many of the power and energy requirements for the vehicle are gravity dependent.

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TABLE I. - SHUTTLE FUEL CELL CHARACTERISTICS

Power, kW	
Continuous	2 to 7
For 1 hr	10
Peak for 15 min	12
Voltage, V dc	27.5 to 32.5
Fuel Cell Power Plant (FCP), kg/kW	7.6
Efficiency, percent	61.8
Service life (@ 4.5 kW)	2000 hr
Tank types	
Hydrogen (2 tanks)	Vacuum-jacketed dewar (1.19 od)
Oxygen (2 tanks)	Vacuum-jacketed dewar (0.965 od)
Pressure vessel	
Material	
For hydrogen	2219 alloy
For oxygen	718 Inconel
Volume, m	
For hydrogen	0.606
For oxygen	0.318
Weight (dry), kg	
For hydrogen	102
For oxygen	97.5
Storage capacity (for hydrogen), kg	41.7
Usable capacity (for hydrogen), kg	37.4
Storage capacity (for oxygen), kg	354
Usable capacity (for oxygen), kg	323

TABLE II. - TRANSPORTATION REQUIREMENTS

External mounted coring drill, kW	10
External power tools, kW	2
Energy Reserve, percent	25

TABLE III. - POWER REQUIREMENTS

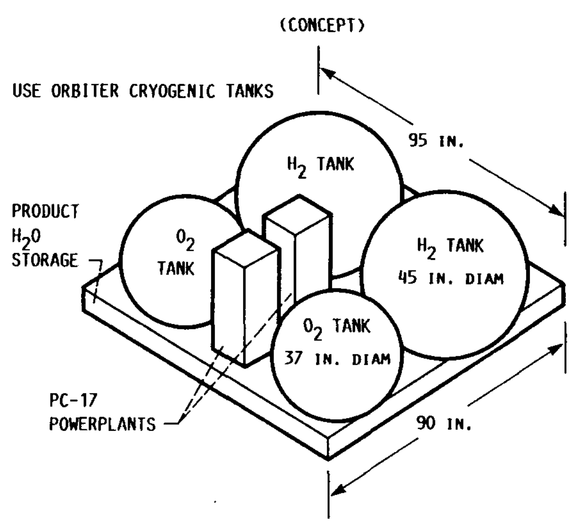
Housekeeping - internal power (ref. 1), kW continuous	2.5
Power reserve, percent (kW)	50

TABLE IV. - FUEL CELL DESIGN PARAMETERS

Power dependent hardware, kg/kW	3.0
Energy dependent hardware, kg/kW	0.44
Reactants, kg/kW	0.57
Efficiency, percent	75
Radiator, kg/kW	5.0
Power management and distribution (PMAD), kg/kW	4.0
Electric motors, kg/kW	1.0

TABLE V. - FUEL CELL SYSTEM COMPONENT WEIGHT BREAKDOWN FOR 16 000-lb VEHICLE

Power dependent hardware	628
Energy dependent hardware	1094
Reactants	119
Radiator	1047
Power management and distribution (PMAD)	847
Electric motors	209
TOTAL	3944



+ 320 FT^2 RADIATOR

CAPACITY
- 1926 KW HR
- 30 KW FOR 64 HR
- 10 KW FOR 193 HR

PULSE CAPABILITY
- 54 KW (51 MIN)
- 125 KW (NAVY REGULATOR, SEC)

	FUEL CELL	Ag-Zn BATTERY
ENERGY DENSITY, WH/LB	~ 504	~ 100
WEIGHT, LB	~ 3800	~ 19 260

FIGURE 1. - 30-KW ORBITER POWER PACK.

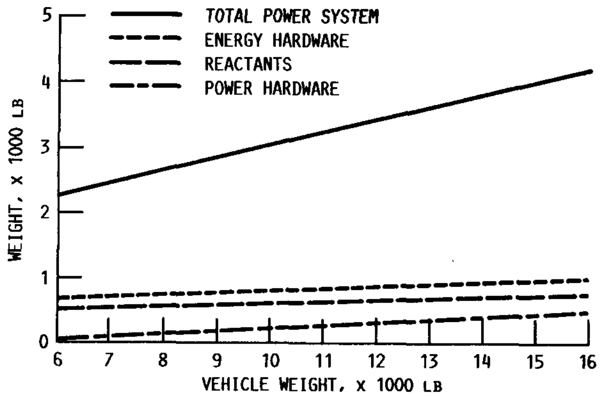


FIGURE 2. - POWER SYSTEM WEIGHT VERSUS VEHICLE WEIGHT.

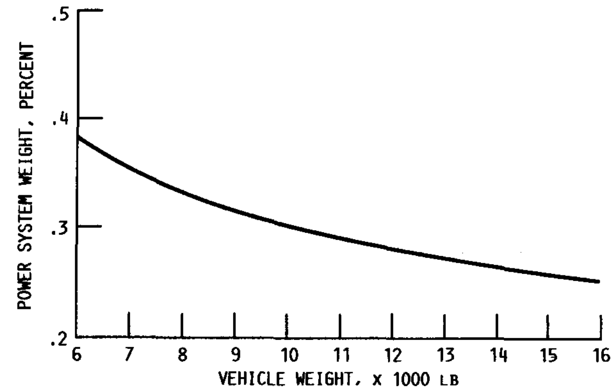


FIGURE 3. - POWER SYSTEM WEIGHT PERCENT VERSUS VEHICLE WEIGHT.

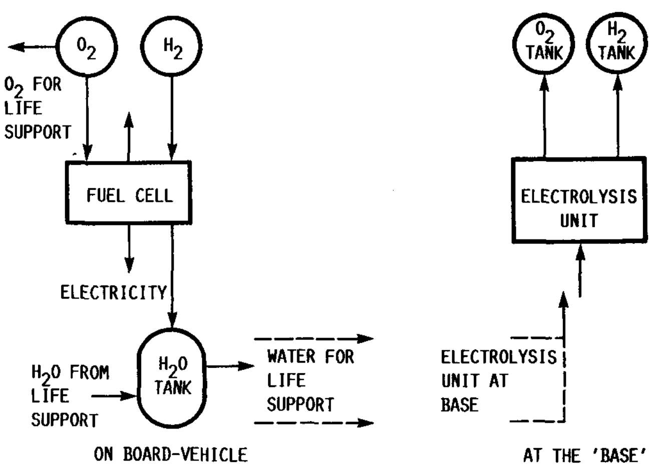


FIGURE 4. - POWER SYSTEM-REGENERATIVE FUEL CELL.

• ENERGY BUDGET	KW-HR
• OVERCOME 100 KM ROLLING RESISTANCE	225
• CLIMBING EFFECT - 50 KM (30 DEG)	188
• 2.5 KW CONTINOUS HOUSEKEEPING	300
• CORING DRILL ENERGY REQUIREMENTS	150
• EXTERNAL POWER TOOLS	40
• TOTAL MISSION DEPENDENT ENERGY REQUIREMENT	903
• 25 PERCENT RESERVE	226
• SYSTEM DESIGN REQUIREMENTS	1129

FIGURE 5. - ENERGY BUDGET FOR 16 000 LB VEHICLE.

• ROLLING RESISTANCE (A)	24
• 50 KM HILL CLIMBING AT 10 KM/HR (30 DEG) (B)	38
• HOUSEKEEPING POWER REQUIREMENTS (CONT) (C)	2.5
• EXTERNALLY MOUNTED CORE DRILL	10
• EXTERNAL POWER TOOLS	2
• FOR POWER SYSTEM SIZING IT WAS ASSUMED THAT A,B,C CAN OCCUR SIMULTANEOUSLY, THEREFORE;	
• FUEL CELL POWER SYSTEM REQUIREMENTS	64
• 50 PERCENT RESERVE	32
• SYSTEM POWER DESIGN REQUIREMENTS	96

FIGURE 6. - POWER BUDGET.

•	POWER	95 KW
•	CELL VOLTAGE (BOL)	.82 V
•	NUMBER OF CELLS/STACK	234
•	NUMBER OF STACKS	1
•	STACK WEIGHT	682 LB
•	STACK DIMENSIONS	69 x 18 x 18 IN.
•	HYDROGEN COMSUMPTION RATE	9.7 LB/HR
•	OXYGEN CONSUMPTION RATE	76.98 LB/HR
•	WATER PRODUCTION	86.69 LB/HR

FIGURE 7. - 95 KW FUEL CELL SYSTEM.

•	POWER	49 KW
•	INDIVIDUAL CELL VOLTAGE	1.63 V
•	NUMBER OF CELLS/STACK	60
•	NUMBER OF STACKS	1
•	STACK WEIGHT	309 LB
•	STACK DIMENSIONS	32 x 21 x 17 IN.
•	HYDROGEN PRODUCTION RATE	2.45 LB/HR
•	OXYGEN PRODUCTION RATE	19.46 LB/HR
•	WATER CONSUMPTION RATE	21.90 LB/HR

FIGURE 8. - ELECTROLYSIS FACILITY.

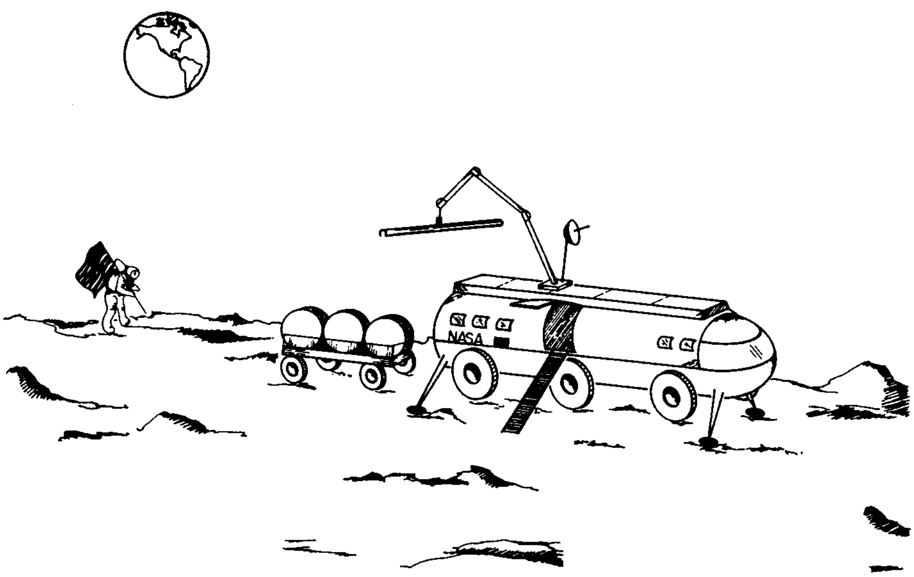


FIGURE 9. - ARTIST CONCEPT OF MARS VEHICLE.

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